Inert doublet DM/extra families in view of Xenon 100, LHC and baryogenesis

Yue Zhang
(ICTP, Trieste)

Based on:
T.Chowdhury, G. Senjanovic, YZ (in progress..)
ArXiv:1105.4611, A. Melfo, M. Nemevsek, F. Nesti, G. Senjanovic, YZ

EW scalar doublet as dark matter

$$H' = \begin{pmatrix} C^+ \\ S + iA \end{pmatrix}$$

- The so-called "inert Higgs" - simplest extension to SM.
- Play the role of cold DM (impose Z2 symmetry by hand), could shed light to the little hierarchy problem.

Despande, Ma, 78'
Baribieri, Hall, Rychkov 06'

- Consistent with EWPT for either heavy or light SM Higgs.

Extra chiral families

- Yukawa perturbativity, cannot be too heavy (<600 GeV)
- Fate to be determined at the LHC soon.

Maltoni, Novikov, Okun, Rosanov, Vysotski, 00'
He, Polonski, Su, 01'
Kribs, Plehn, Spannowsky, 07'

EW scalar doublet as dark matter

$$H' = \left(\begin{array}{c} C^+ \\ S + iA \end{array} \right)$$

- The so-called "inert Higgs" - simplest extension to SM.
- Play the role of cold DM (impose Z2 symmetry by hand), could shed light to the little hierarchy problem.

Despande, Ma, 78'
Baribieri, Hall, Rychkov 06'

- Consistent with EWPT for either heavy or light SM Higgs.

Extra chiral families

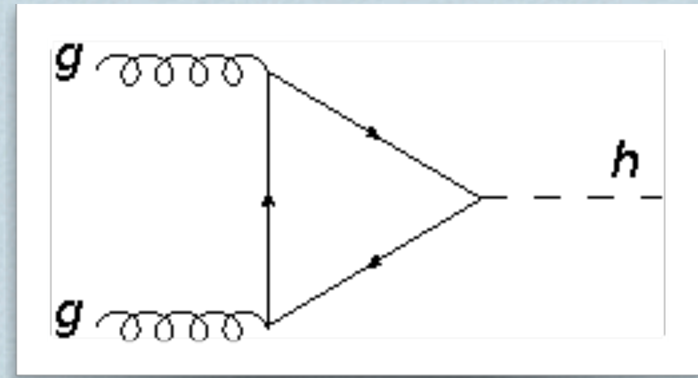
- Yukawa perturbativity, cannot be too heavy (<600 GeV)
- Fate to be determined at the LHC soon.

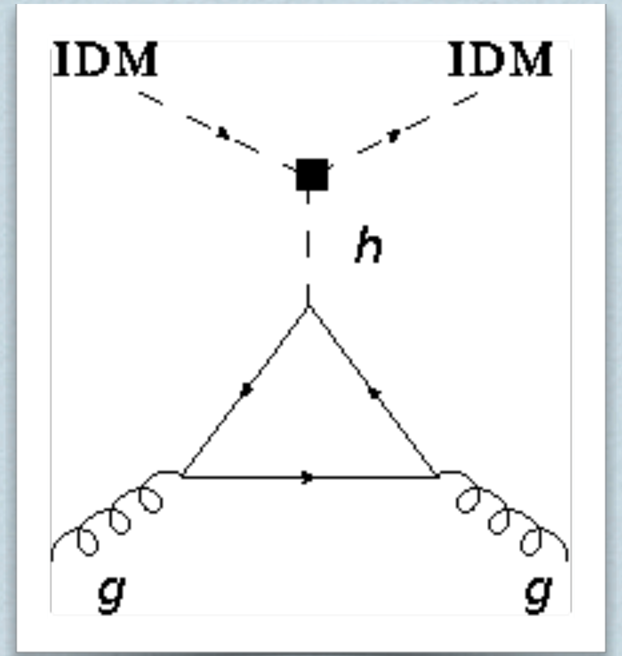
Maltoni, Novikov, Okun, Rosanov, Vysotski, 00'
He, Polonski, Su, 01'
Kribs, Plehn, Spannowsky, 07'

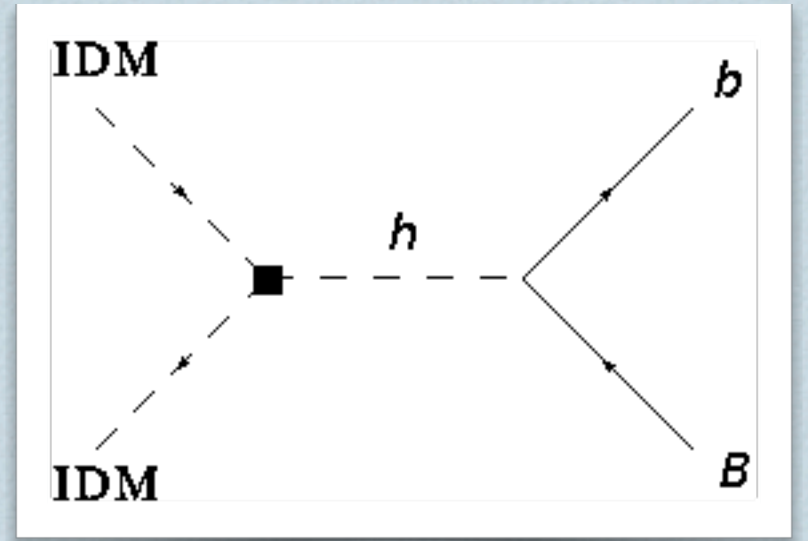
Why talking about them together?

Some connections

- Virtual heavy quarks enhances Higgs-gluon-gluon coupling.
- Higgs mediates DM interactions.
- Interplay among: SM Higgs search at LHC, DM direct detection, thermal relic density.







Melfo, Nemevsek, Nesti, Senjanovic, YZ, 1105.4611

More over..

- Possible explanation of Z_2 symmetry, if with mirror families.
- Message from SM Higgs search at LHC.
- Implication for DM detections.
- Possible connection between dark matter - electroweak baryogenesis.

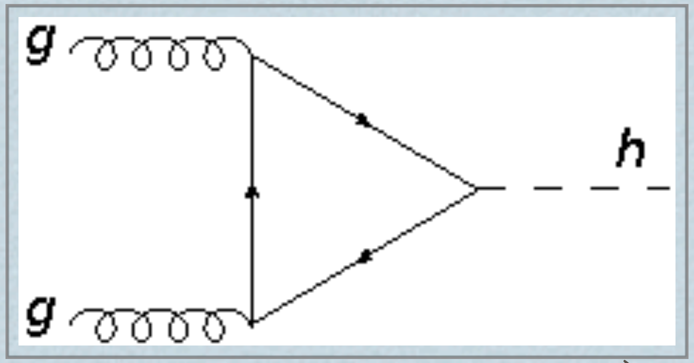
Precision tests & inertness

- Fourth family: consistent with S, T; allows heavier SM Higgs.
- Mirror families? No!
  - S: each heavy fermion doublet $\frac{1}{6\pi}$, making neutrino lighter than Z-boson gives negative contribution.
  - T: Splitting neutrino and charged lepton brings too large T.
- Simplest solution: add a second scalar doublet and split the spectra (cancel T) -- one is enough.
- In order to improve the fit, it wants to be inert: no vev, no mixing with SM Higgs; it has to be lighter than Z-boson.

Melfo, Nemevsek, Nesti, Senjanovic, YZ, 1105.4611
Martinez, Melfo, Nesti, Senjanovic, 1101.3796

SM Higgs Search allows only one extra family

- Production: below 200 GeV, enhancement $(2n+1)^2$ smaller above top-pair threshold.

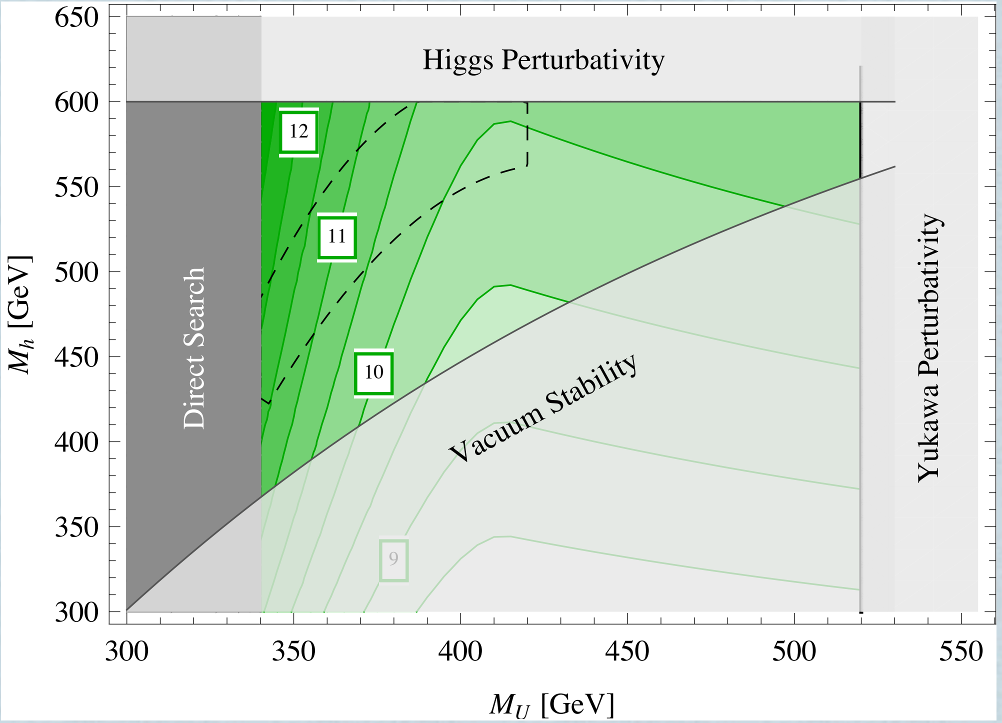


Djouadi, 05'

- Branching ratio (impact on WW channel): could be drastically reduced for light Higgs < 150 GeV, due to new decay channels to dark matter S, extra neutrinos, but very mildly for heavy Higgs.

- Recent LHC results: Mirror case, Higgs must be heavy (stable vacuum), ruled out by LHC (at eps conference).

- For 4th family, light SM between 115-160 GeV still allowed, depending on the spectrum.



SM Higgs must be Light

The inert scalar S as dark matter

$$V = \mu_1^2 + \mu 2^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2 + \frac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + \text{h.c.}\right]$$

- mass spectrum

$$m_S^2 = \mu_2^2 + \frac{1}{2}\lambda_L v^2, \quad (\lambda_L = \lambda_3 + \lambda_4 + \lambda_5)$$
$$m_A^2 = \mu_2^2 + \frac{1}{2}(\lambda_3 + \lambda_4 - \lambda_5)v^2$$
$$m_C^2 = \mu_2^2 + \frac{1}{2}\lambda_3 v^2$$

$$SS \to h \to b\bar{b}$$
$$SS \to (h \to)WW$$

- If A, C heavy (for reasons see later slides), main interactions for relic density
- Direct detection: SM Higgs mediated $\lambda_L SShh$
- Light thermal DM scenario (<45 GeV) is excluded by Xenon due to too large direct detection cross section.

M.-Farina, M.-Kadastik, D.-Pappadopulo, J.-Pata, M.-Raidal, A.-Strumia, 1104.3572

Enhanced cross section & Xenon

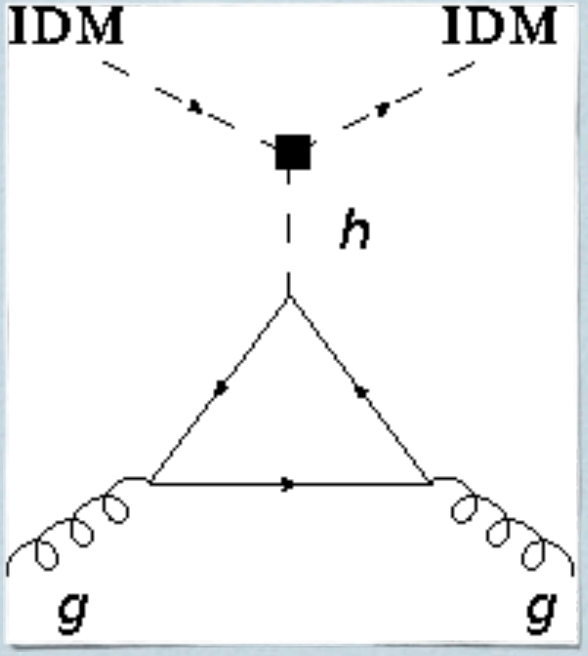
- Direct detection: SM Higgs mediated, isospin conserving

$$\sigma_{SN} = \frac{\lambda_L^2 f(n_h)^2 \mu^2 m_N^2}{4\pi m_h^4 m_S^2}$$

- uncertainty in effective Higgs-nucleon couplings. f

$$\frac{1}{v}\langle N|\sum_q m_q \bar{q}q|N\rangle = \frac{m_N}{v}\left[\left(1+\frac{2n_h}{27}\right)(f_{T_u}^{(N)}+f_{T_d}^{(N)}+f_{T_s}^{(N)})+\frac{2n_h}{27}\right]$$

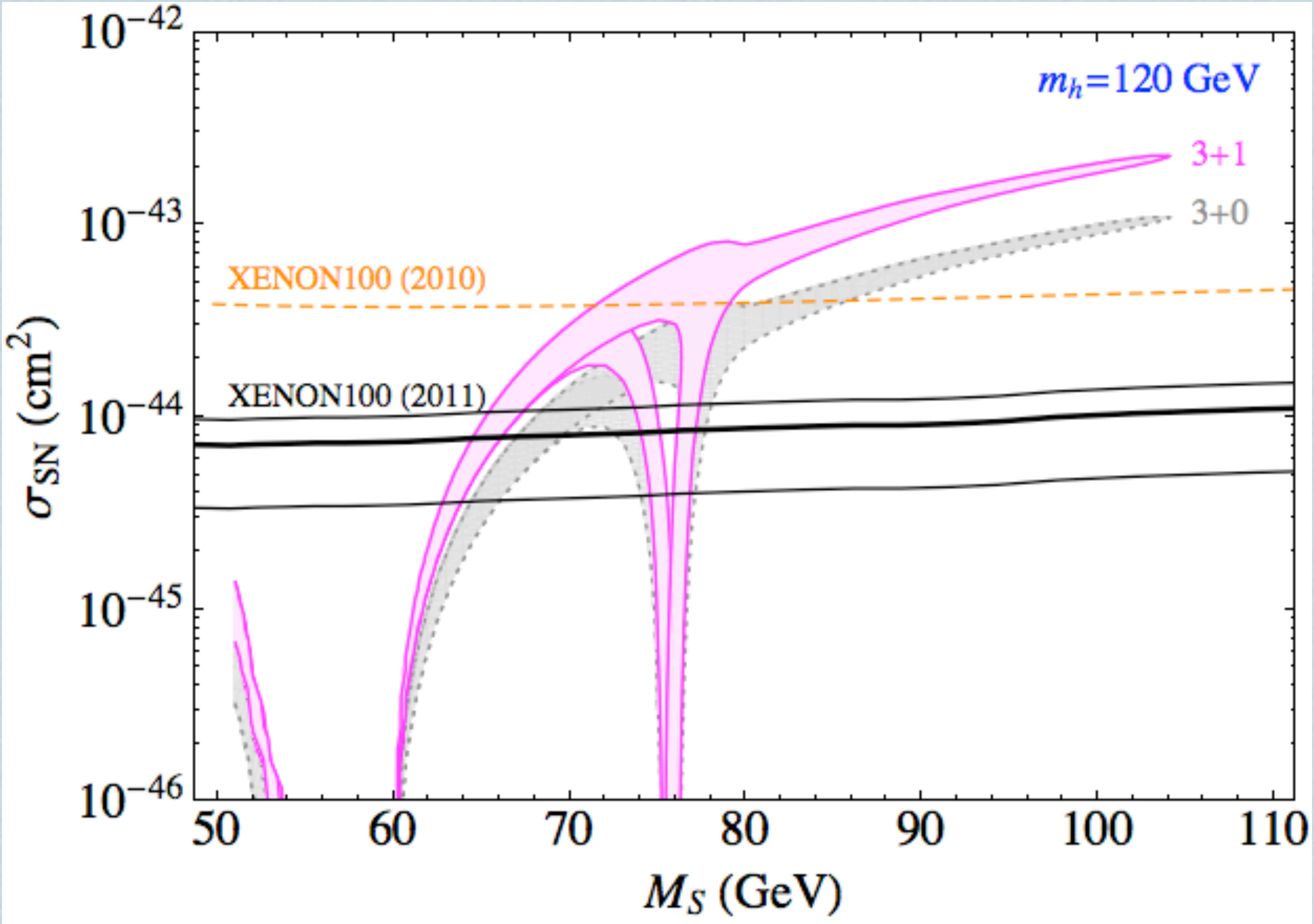
- Uncertainties in strange form factor -- will take lowest f to be conservative, based on recent lattice calculation: SM: f=0.375; 4th: f=0.542; mirror: f=0.875.



- Uncertainties in local DM density.

$$\rho = 0.4 \pm 0.2\ \text{GeV/cm}^2$$

Constraints from Xenon 100

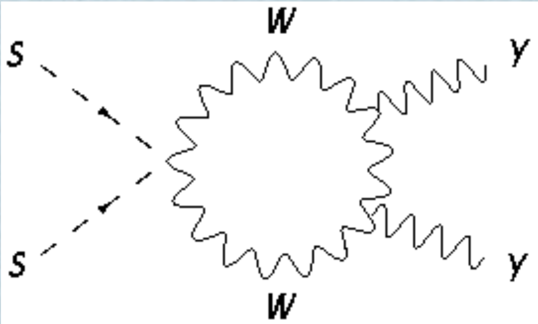


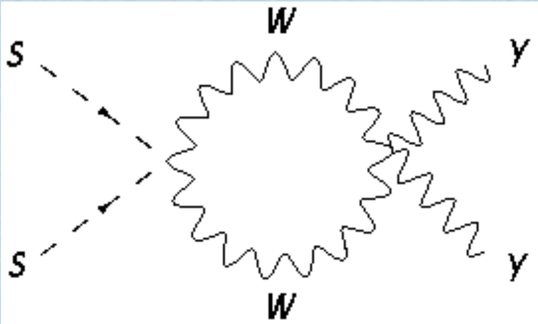
- DM mass: 60-76 GeV:
- Thermal freeze out dominated by SS toWW. Annihilation at low energy: SS to bb and to photons.

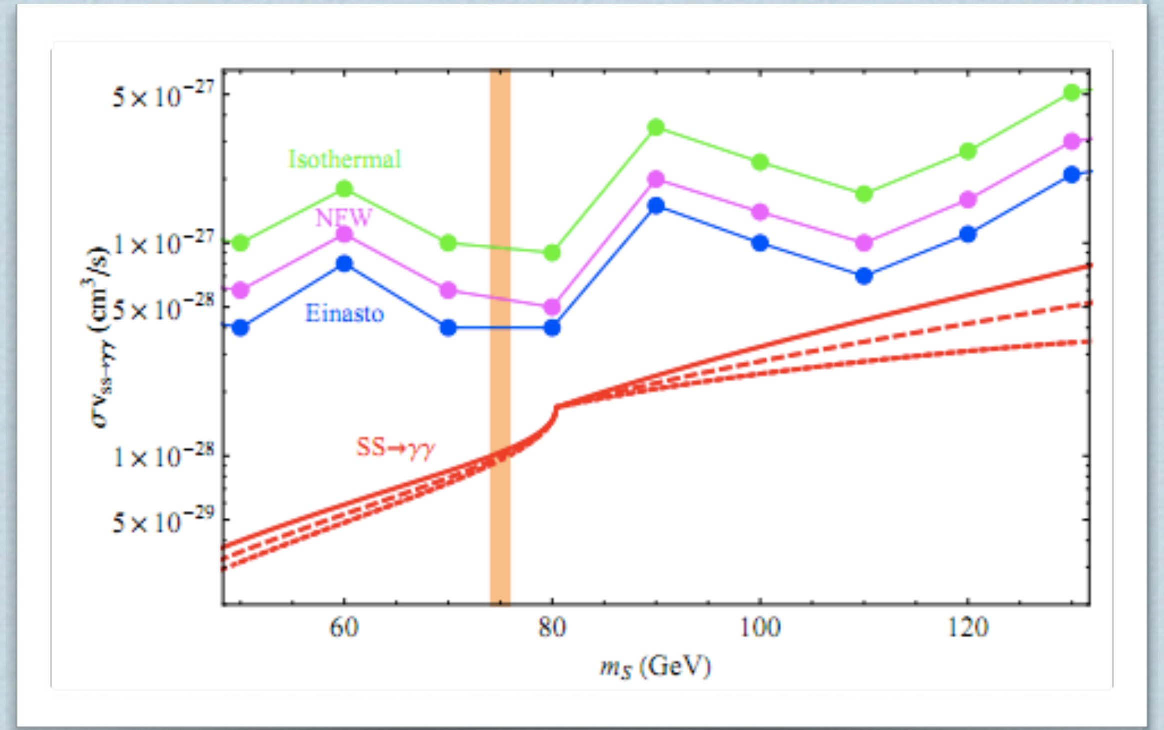
Melfo, Nemevsek, Nesti, Senjanovic, YZ, 1105.4611

Indirect detection

- Mono-chromatic gamma ray from annihilation, calculable.
- The same loop function as Higgs to two photon, dominated by W-loop, fermion loop small.
- Xenon constraint SSh coupling, (almost) exclude possibility of cancellation.
- A lower limit on the annihilation rate.







Connection with EW baryogenesis

- Effective potential at high T: $V_{\rm eff} = \frac{m^2(T)}{2}\phi^2 - ET\phi^3 + \frac{\lambda}{4}\phi^4$
- Strong first order phase transition, $\frac{v_c}{T_c} \gtrsim 1$ cubic term crucial.
- SM: $\frac{v_c}{T_c} \approx \frac{3}{2\pi}\frac{2M_W^3 + M_Z^3}{m_h^2 v_0}$ need Higgs lighter than 50 GeV.
- With an inert doublet, term proportional to T

$$-\frac{T}{12\pi}\left[m_S^3(T) + m_A^3(T) + 2m_C^3(T) + 4M_W^3(T) + 2M_Z^3(T)\right]$$

- Thermal mass not purely cubic term (similar to MSSM stop)

$$m_i^2(T) = \left(\mu_2^2 + \epsilon_i \frac{T^2}{12}\right) + \lambda_i \phi(T)^2, \quad (i = S, A, C)$$

- None-zero first term tends to weaken the strength of phase transition -- upper bound on μ_2^2 (better negative).

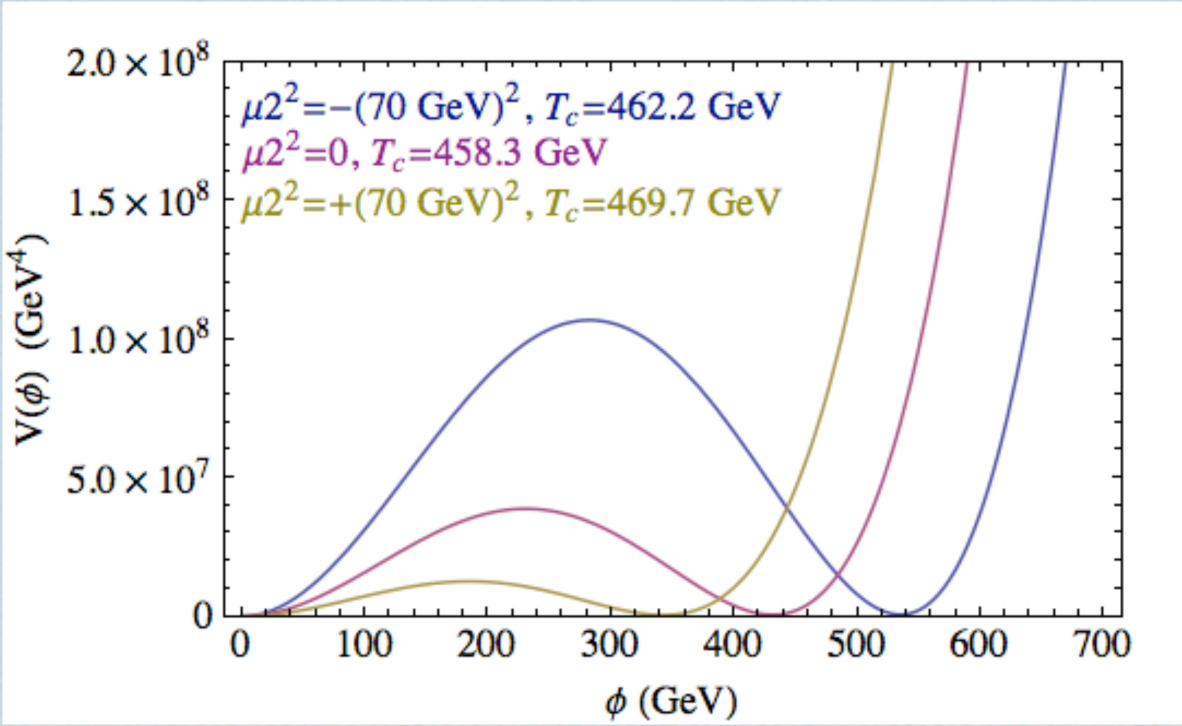
Connection to direct detection

- Given A, C masses, upper bound on μ_2^2 .

$$m_S^2 = \mu_2^2 + \frac{1}{2}\lambda_L v^2 = 60 - 76\,\mathrm{GeV}$$

- Lower bound on λ_L

- Remember λ_L controls direct detection cross section.



T.Chowdhury, G.Senjanovic, YZ, in progress

- Strong enough EWPhT implies a lower bound on DM direct detection rate!

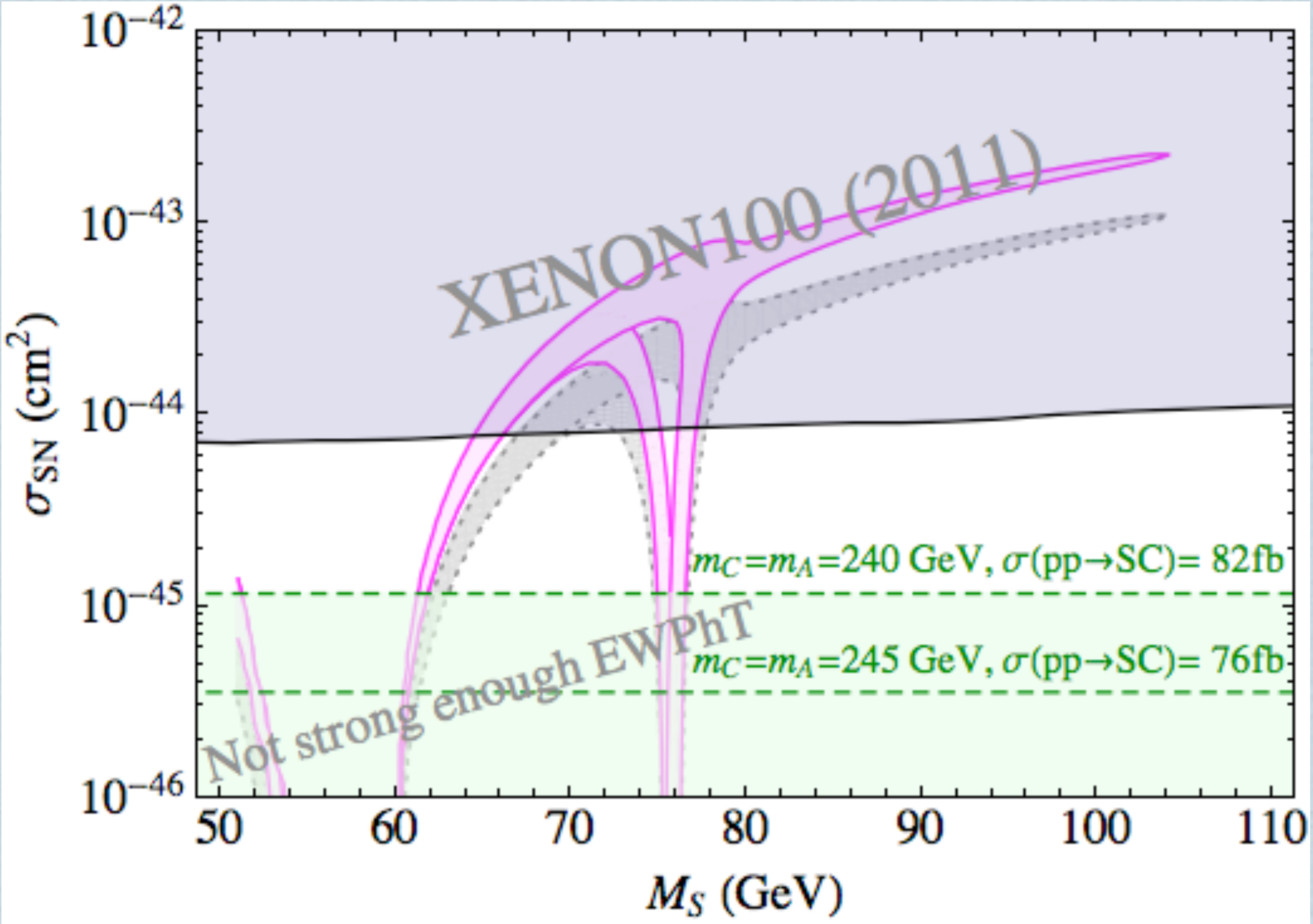
- Only works in a window of A, C mass: 200-300 GeV.

- No CP phase in the Higgs potential, need 4th generation.

Connection to LHC

- Associate production SA or SC through Z or W.
- Missing energy plus n leptons (n=1,2), relaxing the missing ET cuts will help discovery.

See talk by Shufang Su on Monday



T.Chowdhury, G.Senjanovic, YZ, in progress

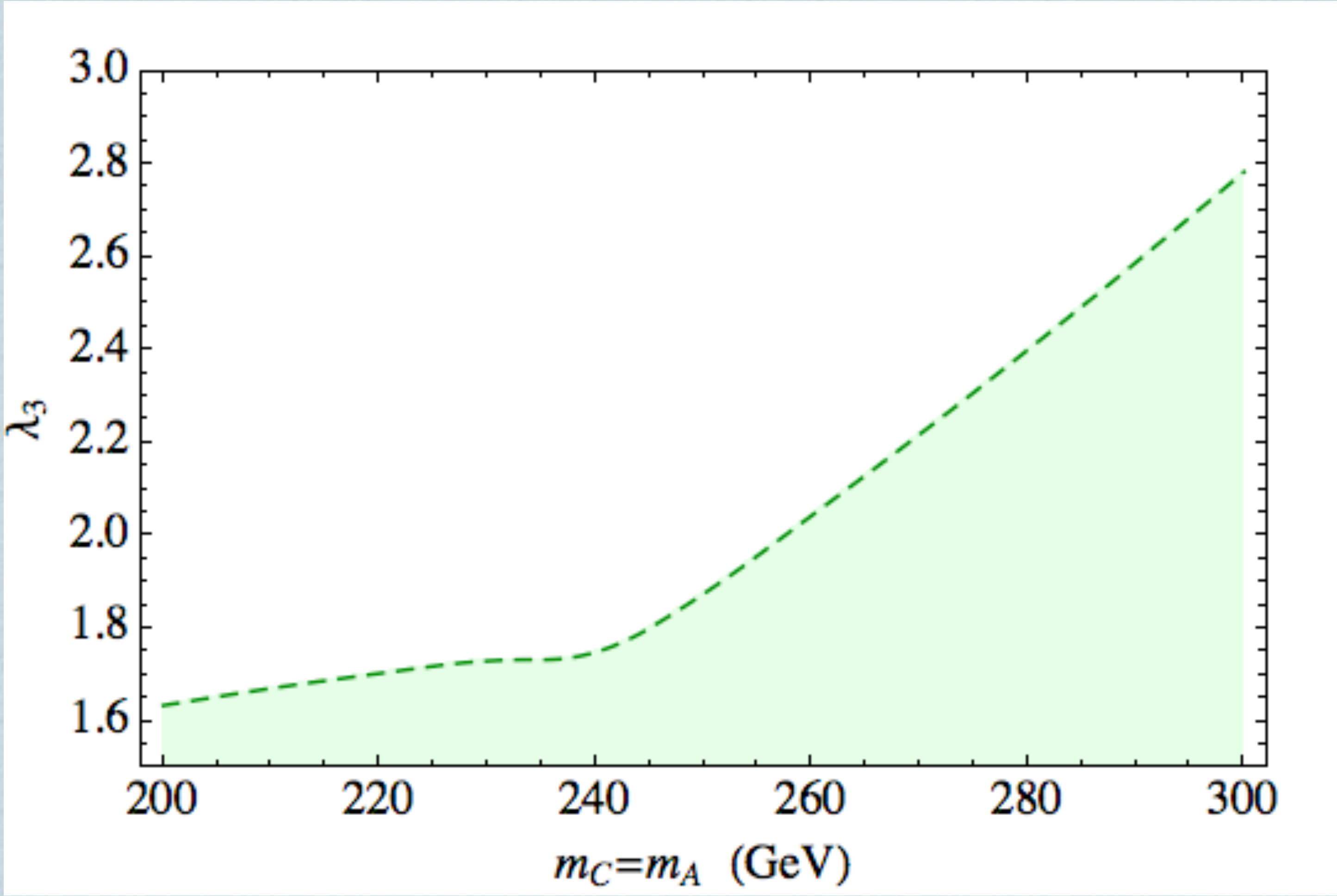
Conclusions

- Inert doublet dark matter is a very interesting scenario in presence of extra families.
- Enhance Higgs mediated DM-nucleon interaction, interesting correlations among DM direct/indirect detections, relic density and LHC Higgs searches.
- Possible dark matter - baryon asymmetry connection.
- Heavy extra quarks will soon be excluded or established at LHC.

Conclusions

- Inert doublet dark matter is a very interesting scenario in presence of extra families.
- Enhance Higgs mediated DM-nucleon interaction, interesting correlations among DM direct/indirect detections, relic density and LHC Higgs searches.
- Possible dark matter - baryon asymmetry connection.
- Heavy extra quarks will soon be excluded or established at LHC.

Thank you!



3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
λ_3
200
220
240
260
280
300
m_C=m_A (GeV)